NASA TECHNICAL NOTE

NASA TN D-6088
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NASA TN D-6088

DESIGN AND OPERATING CHARACTERISTICS OF A CENTRALIZED ON-LINE DATA PROCESSING SYSTEM AT LANGLEY RESEARCH CENTER

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • DECEMBER 1970

1. Report No. NASA TN D-6088	2. Government Accession No.	3.
4. Title and Subtitle DESIGN AND OPERATING CHARACTERISTICS OF A CENTRALIZED ON-LINE DATA PROCESSING SYSTEM AT LANGLEY RESEARCH CENTER		5. Report Date December 1970
		6. Performing Organization Code
7. Author(s) Sheldon Kopelson and Joseph D. Nolan		8. Performing Organization Report No. L-6415
		10. Work Unit No. 125-23-04-02
9. Performing Organization Name and Address NASA Langley Research Center Hampton, Va. 23365		11. Contract or Grant No.
		13. Type of Report and Period Covered Technical Note
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D.C. 20546		14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

This paper describes a centralized on-line data processing system providing concurrent service for five test facilities. A real-time data acquisition program and a quasi real-time data reduction program operate in a multiprograming-multiprocessing computer which is interfaced to a central data recording facility serving a large number of test sites. Computed results are returned through a remote terminal system. Five non-time-critical programs may execute in the computer along with the on-line software. Memory requirements for the on-line software are minimized by automatically adjusting the field length of the data acquisition program to the number of active sites and by overlaying all test site data reduction subprograms in a common memory area. Central processor time is a function of data sampling rates. The possibility of a disastrous failure in a newly added data reduction overlay was anticipated and special protective software insures the operation of the system for the remainder of the test sites.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
On-line data processing Centralized recording	Unclassified – Unlimited

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
Unclassified	Unclassified	40	$3.00

*For sale by the National Technical Information Service, Springfield, Virginia 22151

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SUMMARY

This paper describes an on-line data acquisition and reduction system which has been implemented as part of the digital computer complex at the Langley Research Center. Up to five research facilities can be served by the on-line data system at the same time. However, each facility is afforded independent test scheduling and data reduction programing.

The software for the on-line data system operates in a multiprograming computer environment that provides for the concurrent execution of a number of unrelated programs. A single program which operates in real time is used for all on-line data acquisition. A second program operating with high priority but not in real time incorporates the data reduction subprograms of the facilities. The computer memory used by the on-line data system adjusts dynamically with the number of facilities served. Central processor time is a function of data sampling rate. The unused computer resources are always available to the non-time-critical programs that are being executed during on-line activity.

Data acquisition from the research sites is accomplished through an interface between a central recording facility and the computer complex. Computed results are returned to the sites by means of typewriter-speed remote terminals. One terminal in the central recording area is used to execute dynamic control over the on-line programs.

The concepts that were employed in developing the on-line data system's software resulted in high efficiency of computer resource usage while the independence and integrity of research facility operations were maintained.

INTRODUCTION

In several areas of aerodynamic research, the complexity of testing and analysis has grown significantly in recent years. Consequently, it has been evident for some time that the cost and time required to complete many studies can be significantly reduced if the results of key computations involving a set of data are made available – at the test facility – within a short time after the data are acquired. By use of this information, succeeding test conditions or model configurations can be chosen so that only the significant ranges are covered. However, the nature of the calculations and the necessary speed of response often require the use of a large-scale digital computer in the on-line data-acquisition—reduction loop. Since test operations are characterized (in the long term) by short periods of activity at random intervals, the cost of the computer resources cannot be overlooked in choosing among the approaches available for providing the necessary computer resources. One approach requires an individual computer of sufficient power at each test facility. In another approach, a centrally located computer is used to perform on-line data reduction for a number of facilities as well as a background workload of off-line scientific computation. This approach requires that the on-line capability accommodate the differences in the operations and data reduction requirements of the various test facilities. This report describes the design and operating characteristics of a centralized on-line data system.

The implementation of the on-line system involved interfacing an existing central recording facility to the digital computing complex at the Langley Research Center. However, the need for an on-line service was recognized for some time before the acquisition of third-generation computers with true multiprograming capability. In fact, an on-line service had been previously implemented which employed a remote terminal system to link the data recorders to the computer then in use. Although data acquisition rates were limited as a result of this linkage, the experience gained through using this system substantiated the effectiveness of a centralized operation and led to the performance criteria for the on-line data system described in this report.

The paramount requirement for a centralized on-line data system was that the operations of the test facilities be permitted to remain as independent as possible. This requirement resulted in a system designed to meet the following criteria:

(1) Easy integration of data reduction subprograms specifically designed for each test facility and each new test

(2) Input of data from a test facility through any of the five data acquisition systems

(3) Response time commensurate with test facility requirements

(4) Independent initiation of operations for each test facility

(5) Direct control by the test facility of the start of data acquisition, the sampling rate, and the start of data reduction.

(6) The ability to change – between runs – the parameters used by the data reduction subprogram of the facility.

The first criterion had the greatest impact on the design of the on-line system software. In order to meet this criterion while insuring the integrity of the real-time data acquisition function, the data acquisition and data reduction functions were separated. However, the additional goal of efficiently utilizing the computer's multiprogram capability so that nonrelated programs could execute concurrently with on-line operations was pursued by assigning all data acquisition for up to five test facilities to one program and all data reduction to a second program.

The multiprograming computer environment in which the software for the on-line data system operates provides for the concurrent execution of up to seven unrelated programs. The computer used for this system has 10 peripheral processors with small independent memory units. A parallel processing technique is employed so that one program may be using the central processor for computation simultaneously with other programs' use of peripheral processors for input, output, and other supporting tasks. Five non-time-critical programs may execute concurrently with on-line activity.

The data acquisition program dynamically adapts its memory requirement to the number of facilities that are actively on-line. Data reduction subprograms unique to each facility operate under a single executive-type program but share a common memory area in the computer. Thus, the amount of memory required to reduce data for five facilities is not much more than that required for one. Incorporating five facility-oriented data reduction subprograms in this manner, however, created the potential hazard of a failure in one subprogram terminating the operations of all facilities that would be on-line at that time. The burden of preventing this occurrence was added to the supervisory activity of the executive program. The full implementation of this concept required making related modifications to the computer's operating system software.

The central processor time used by the on-line software varies with the rates of data sampling and data reduction requests. The memory and processor time that are not used are available to the non-time-critical programs that are being executed at any time during on-line activity.

The data input link to the on-line data system is provided by the central recording facility and interfaces between it and the computer complex. Computed results are returned to the test sites by means of a remote terminal subsystem and are available well within 1 minute after an input code requesting data reduction is sensed. A remote terminal is used by the operator of the recording facility to control the software's connective logic and to change data reduction parameters in response to the needs of the test facilities. This report describes the central on-line data system at the Langley Research Center with emphasis on its software design. The integration of the on-line data system with the computer operating system is also described. It is felt that the concepts that are thus presented are applicable to centralized on-line data systems using other multiprograming computers and data acquisition systems.

A glossary of the terms applicable to this system is given in an appendix.

THE CENTRAL DATA RECORDING FACILITY

The Langley central digital data recording facility presently serves 21 research facilities for digitizing and recording (on magnetic tape) aerospace test data such as the output of strain gages, thermocouples, and pressure transducers. The most remote research facility is located 3300 cable feet from the recording facility; the limit is one cable mile.

As illustrated in figure 1, the recording facility consists of five Beckman Model 210 data acquisition systems; their characteristics are listed in table I. Input data lines from the research facilities are connected to the data acquisition systems through a patchboard switching system that permits all but a few of the facilities to be connected to any of the data acquisition systems. Three facilities can be connected to the 240-channel system or to either of two other systems when recording only 120 channels of data.

TABLE I.- CHARACTERISTICS OF BECKMAN MODEL 210 DATA RECORDERS

Input channels:	
Recorders 1, 3, 4, 5	100 analog; 20 digital
Recorder 2	220 analog; 20 digital
Amplifiers (1 per analog channel):	
Ranges, mV	±6.25, 12.5, 25, 50, 100
Input impedance, megohms	>100
Sine wave response	99 percent at 2 Hz
Digitizing scale	±9999 counts
System accuracy	0.1 percent full scale
Maximum noise	±3 counts
Sampling rates	20 samples/second/channel (120 channels)
Output format	Binary coded decimal; four characters plus sign per channel, 120 channels per record
Output record	15 000 characters/second

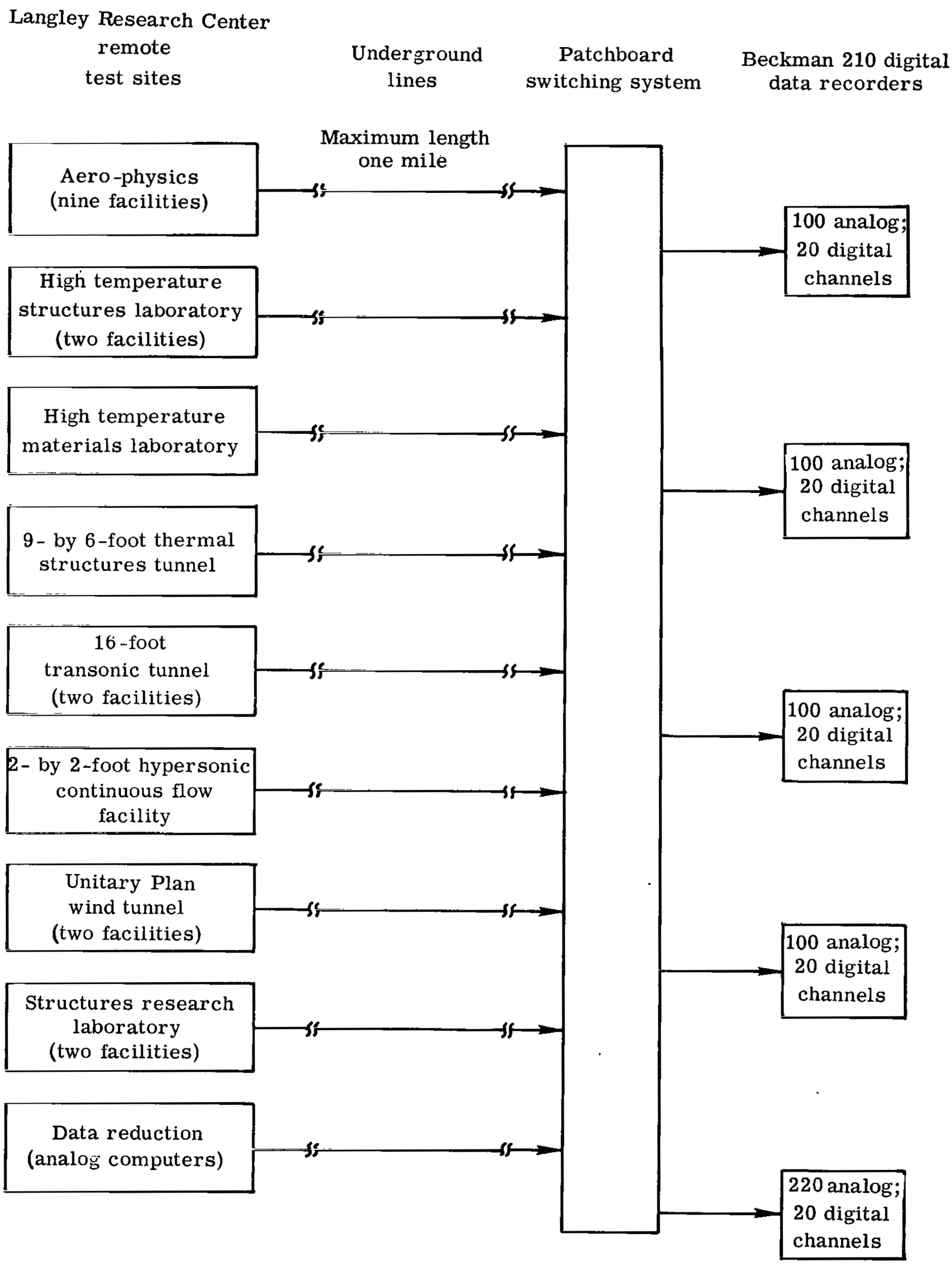

Figure 1.- Schematic of central data recording system.

The flexible switching system minimizes operational scheduling conflicts. The on-line data system retains this flexibility and also permits the recording facility to be operated with any combination of on-line and off-line activity.

After a data acquisition system is readied, control of its operation is transferred to the test site. The remote control capability includes: single frame recording, start and stop of continuous (that is, 20 records per second) recording and return of control to the central recording facility.

THE DIGITAL COMPUTER COMPLEX

The configuration of the Langley digital computer complex, which is illustrated in figure 2, consists of four independent Control Data series 6000 computers and a shared peripheral pool of input-output equipment. Communication between the computers and the peripheral equipment is accomplished through a number of multi-access electronic switches which operate under either manual or program control so that any computer can communicate with any peripheral device.

The configuration subset that is required for the on-line data system is shown in figure 3. The on-line programs decks are read into one of the 6000 series computers by means of a peripheral card reader. Once the programs are executing in the computer, data are acquired through the data acquisition interfaces and are stored in disk files until computation is initiated. Computed results are returned by the IBM 7740 line supervisor to low-speed remote terminals at the test sites. The low-speed remote terminal system is also used for the input of dynamic control information and the output of status statements regarding the overall operation of the on-line data system.

Other devices in the peripheral equipment pool may be used as needed to support the non-time-critical programs that are executed in concurrence with the on-line activity. The low-speed remote terminal subsystem is the input-output medium for a large number of these non-time-critical programs.

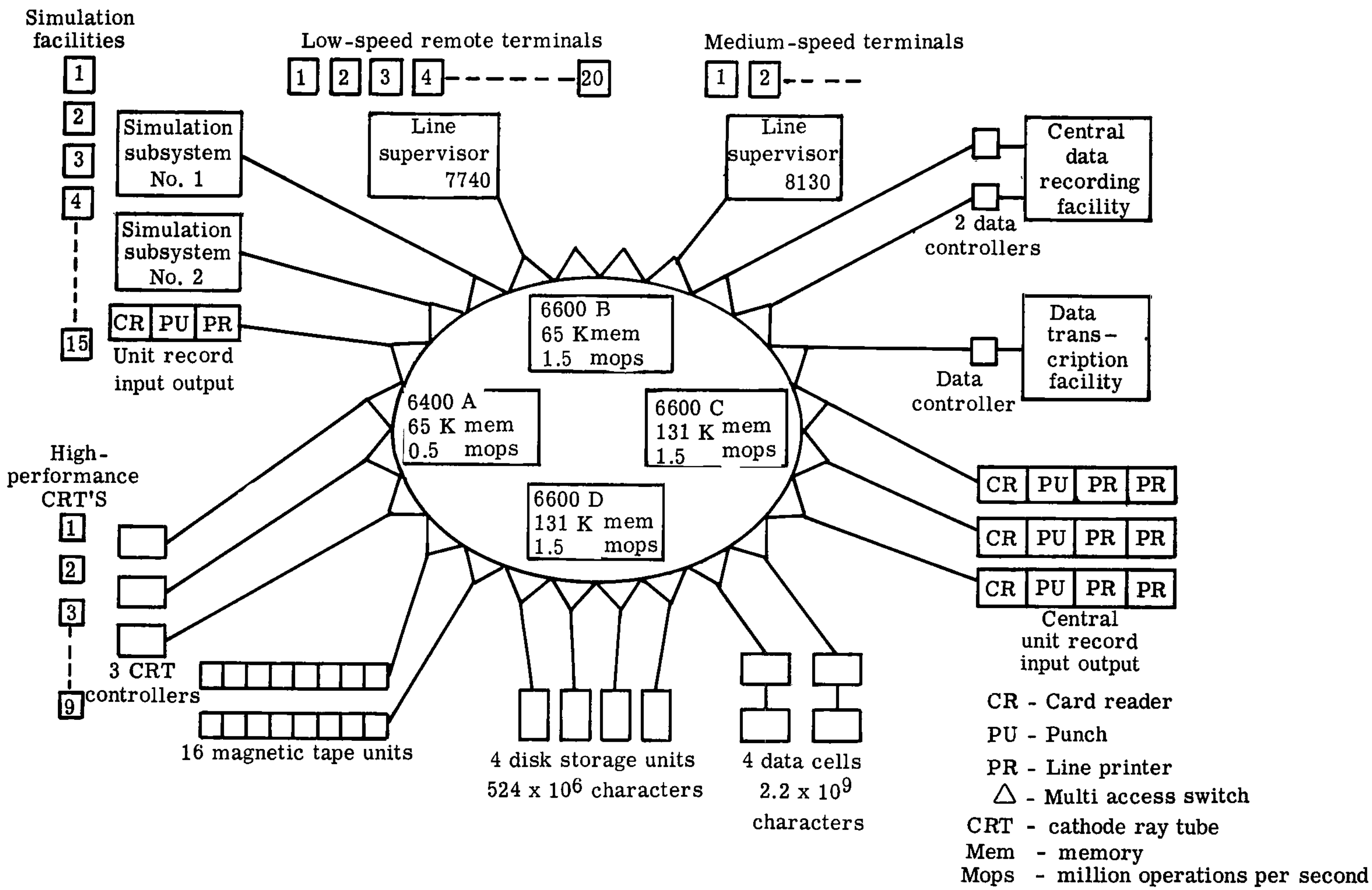

Figure 2.- Digital computer complex.

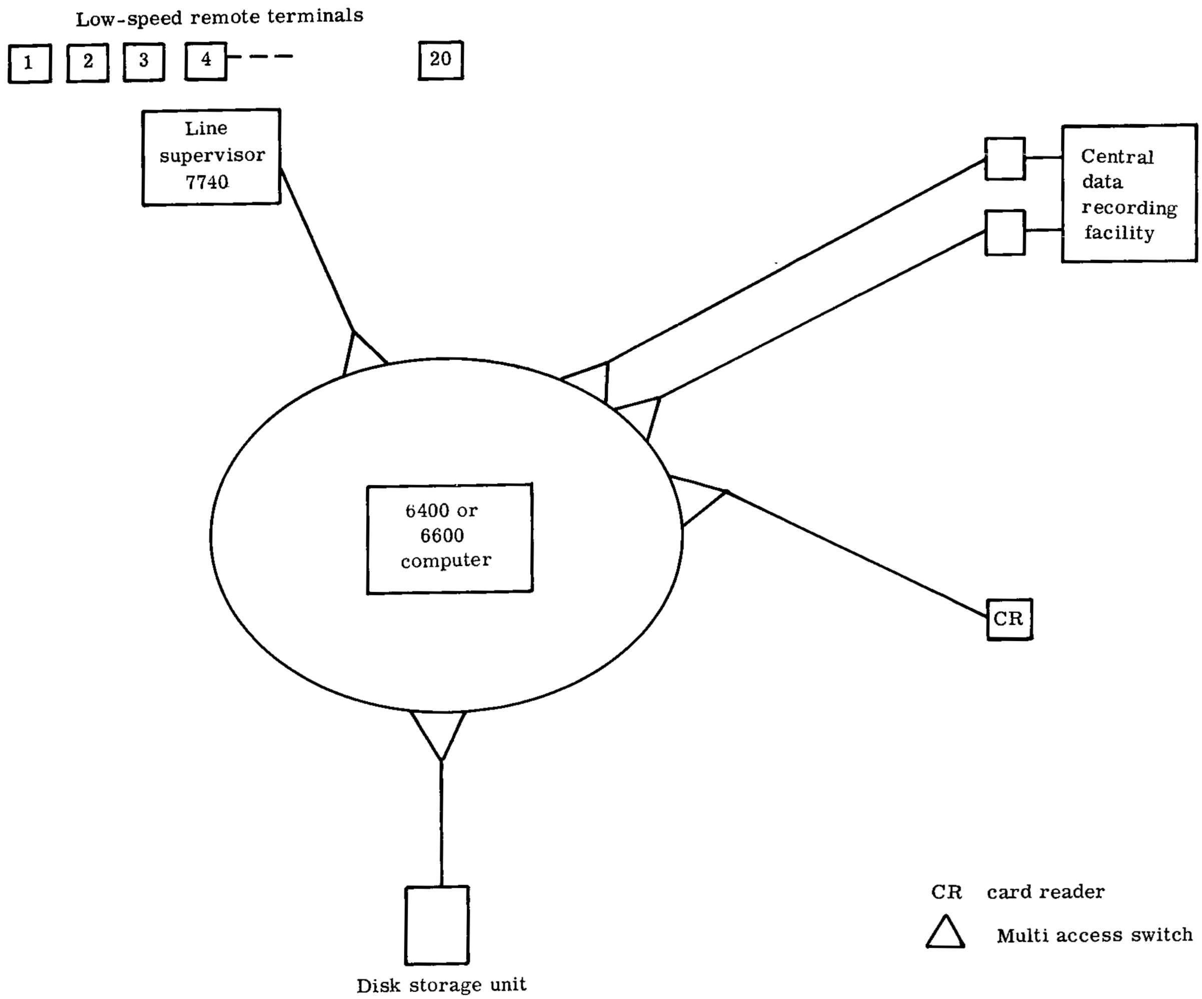

Figure 3.- Partitioned configuration for on-line data system and batch processing.

COMPUTER ORGANIZATION AND OPERATING SYSTEM

The organization of a Control Data 6400 or Control Data 6600 computer (ref. 1) is illustrated in figure 4. The central processing unit operates only on programs stored in central memory. The 10 peripheral processors of the computer, each of which is effectively a separate computer with 4096 (12 bit) words of memory, communicate with all input-output equipment (by use of the 12 half-duplex channels), the central processor, and the central memory. The central and 10 peripheral processors operate in parallel.

The computer operating system allows up to seven different application-oriented programs to reside in central memory and execute in a multiprogram mode. During execution, the index of jobs is a control point number (1 to 7). Each of the seven control points has an area in central memory that contains all the information necessary to define and process the job. One of the 10 peripheral processors is used for the continual execution of the real-time monitor of the operating system – the program that controls all other computer system activity. A display and control program resides permanently in one of the other peripheral processors to provide continual dynamic display and control for operator communication by means of a cathode ray tube and console typewriter. The remaining peripheral processors constitute a pool of support capability which, upon command from the monitor, will perform various input-output and control tasks required for the execution of the programs in central memory.

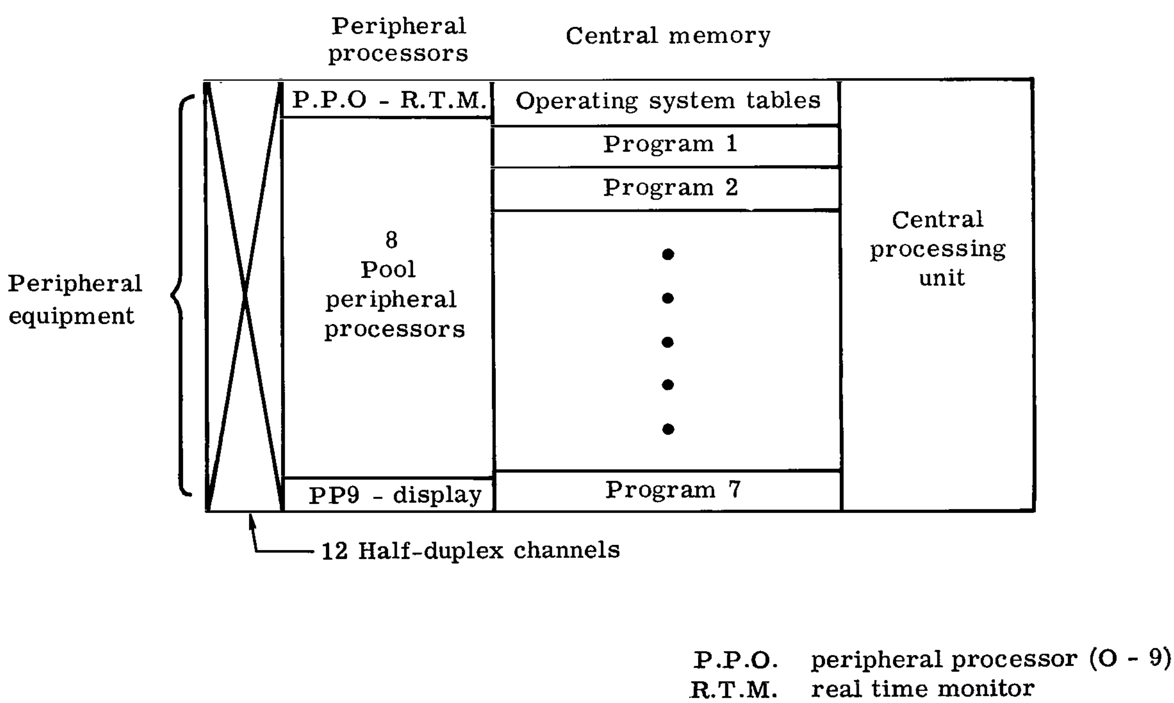

Figure 4.- Organization of a Control Data 6000 series computer.

The prime feature of the real-time monitor is its ability to respond to requests from time-critical programs within a definable time under all conditions of computer activity. (See ref. 2.) The current real-time monitor has a worse-case response time of 200 microseconds to a request from a real-time program. This monitor response time and other timing considerations such as access to disk storage were significant factors in determining the structure of the software needed to meet the criteria for the on-line data system.

ON-LINE DATA SYSTEM CHARACTERISTICS

Hardware Configuration

Figure 5 is a functional diagram of the equipment configuration of the on-line data system. Each data recorder in the central data recording facility can be operated in an off-line mode in which data are recorded on magnetic tape or in an on-line mode with data being transmitted to the computer while it is being recorded on the tape.

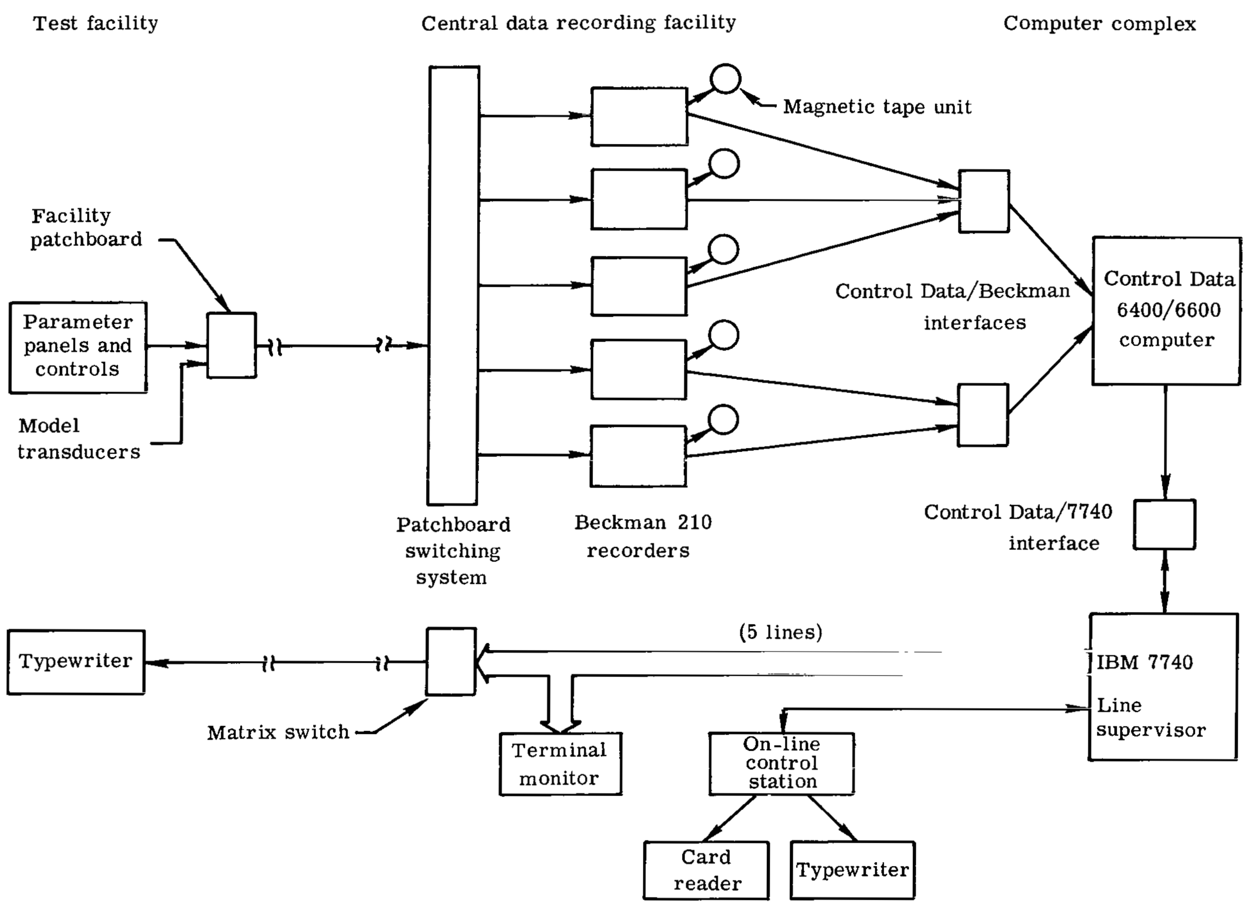

Figure 5.- On-line equipment configuration.

At test sites for which on-line service is provided, two items are added to the normal site equipment. One is a "compute" control which the site operator activates to initiate the reduction of a file of data. The other item is a remote terminal typewriter which is used to print the computed results.

The Beckman Control Data interfaces (refs. 3 and 4) are buffers which permit the computer to acquire data from the Beckman recorders which operate asynchronously with respect to the computer (and each other) as the result of test site control of the start of data acquisition and the sampling rate. The system hardware includes interlocks so that a recorder operated in the on-line mode cannot be started until the computer is prepared to acquire the data.

The remote typewriters are connected to five of the low-speed terminal system lines by a matrix switch. The patchboard connection of the input data lines of a test site to a particular recorder controls the connection of its typewriter to the terminal line associated with that recorder.

Software Characteristics

The primary on-line software consists of a data acquisition program and a data reduction executive program. These programs operate independently at computer control points 1 and 2. Both of these programs are dynamically controlled by the operator of the central recording facility.

The real-time data acquisition program acquires data from up to five recorders operating at the maximum sampling rate. On-line activity of the recorders may be started and terminated in any order. As the data are received, the data for each recorder are stored in a separate logical file in disk storage. When a compute request is received from a particular facility, the current file of data for that test facility is made available to the data reduction executive. A new file is opened in anticipation of the next set of data that the test site may wish to record.

The data reduction executive performs all communications and control activities for up to five applications subprograms (incorporated as overlays) operating concurrently. Each overlay is, in essence, a unique program that meets the distinctive data reduction requirements of a particular test facility for a given test. The overlays reside temporarily in disk storage and the proper one is called to a shared memory area when a computing request from a test site is sensed. When the data reduction for a given computing request has been completed, the results are sent to the test facility by means of the remote terminal subsystem.

Control

Overall control of the system is exercised by means of a remote terminal in the central recording area. These controls are: specifying to the data acquisition program the data recorder to which the computer is to connect and the first file name to assign to data from that recorder, furnishing the data reduction executive program with the information needed to make the logical connection between the individual data reduction overlay of a research facility and the data recorder to which that facility is connected, and changing an overlay's parameters to match a change in test parameters at the research facility.

The computer operating system software for the remote terminal system recognizes and responds to the request for the direct creation of files of information which may then be searched for by executing programs. Card decks for on-line system control contain a unique file name and the description of required function.

Status Monitoring

During on-line operation both the data acquisition program and the data reduction executive send status messages to the control terminal. There are three types. The first indicates a normal operation such as the response to a control instruction or the opening of a new data file. The second message category covers erroneous control instructions. The third category describes on-line system malfunctions – should they occur.

Terminal lines are monitored at the central recording area whenever the parameters of an overlay are changed. Overlays transmit a copy of parameters to the test facility for verification. The operator's duplicate provides a reference if the facility requests a further change.

Typical Operation

Before the start of a period of on-line activity, an on-line program card deck is assembled which contains the following units: (1) a control deck which will cause the data acquisition program to be loaded into the computer memory from disk storage, (2) a control deck which will cause the data reduction executive program to be loaded into the computer from magnetic tape, (3) the data reduction overlays for the test sites that plan to operate during the given period of on-line activity, and (4) the overlay parameters that each facility plans to use for at least its first run. The executive program loads the overlays which, in turn, read in their parameters.

The on-line program deck is read into the computer when one of the test sites notifies the central recording facility that it is prepared to conduct a test. At the same time, the central recording facility operator selects and prepares an available data acquisition system. The preparation includes setting analog channel gain settings to the values required by the test site as well as making the necessary patchboard connections.

During the preparation of the data acquisition system, the on-line programs remain in an idle status. Their activity starts when control decks are read into the remote terminal. In response to its control deck, the data acquisition program expands its buffer memory, opens the specified data file, and causes the connection to the specified data acquisition system. The data reduction executive makes the logical connection between the acquisition system number and the data reduction overlay of the test site.

Control of the data acquisition system is transferred to the test site upon request. Data may be sampled and digitized at a continuous rate of 20 frames per second or on a single frame basis. The latter may be activated manually or by a suitable sequencer. Activation of the compute control at the test site results in transfer of the file of data thus generated from the data acquisition program to the data reduction executive. The latter calls the proper overlay to reduce the data and transmit the results to the test site. The test site may restart data sampling as soon as the data acquisition program has opened a new data file. Also, at its request, the data reduction parameters for the next file can be changed by entering a control deck containing the new parameters in the central recording remote terminal. In most cases, test conditions for each run are chosen from a number of preplanned alternatives and the new parameter cards are chosen from a prepunched set.

On-line activity for the other test sites follows the procedure described, and starts with the selection of an available data acquisition system. Test sites may also terminate their on-line activity in any order. With each termination the program-acquisition system connections are broken and the data acquisition program returns a memory buffer increment to the pool that is available to non-time-critical programs. Termination of the data acquisition and data reduction executive programs is accomplished by means of card decks read in at the control terminal.

COMPUTER-RECORDER INTERFACE

Two interface units (ref. 3) provide the buffering needed so that the computer can input data efficiently from the recorders, which operate asynchronously with respect to each other. Each interface unit can service three recorders.

The data input from each recorder is serial by character. Each character consists of seven parallel bits; 1, 2, 4, 8 (binary coded decimal code), A, B, and C (parity) accompanied by a clock pulse. A recorder word (digital value of a channel) consists of four characters for magnitude and a fifth character containing numeric zero and the representation of the sign. The computer, through a peripheral processing unit (PPU) accepts information in 12 bit bytes. The interface assembles the incoming characters from each recorder into two bytes in the format shown in figure 6. Each of the first four input characters is contained in a six bit half-byte. Bit A of the most significant half-byte is set if the recorder word is negative. Should a parity error occur in a character, the occurrence is flagged by setting the B-bit in the half-byte. A parity error in any of the five characters is indicated in a message status byte which serves all recorders connected to one interface.

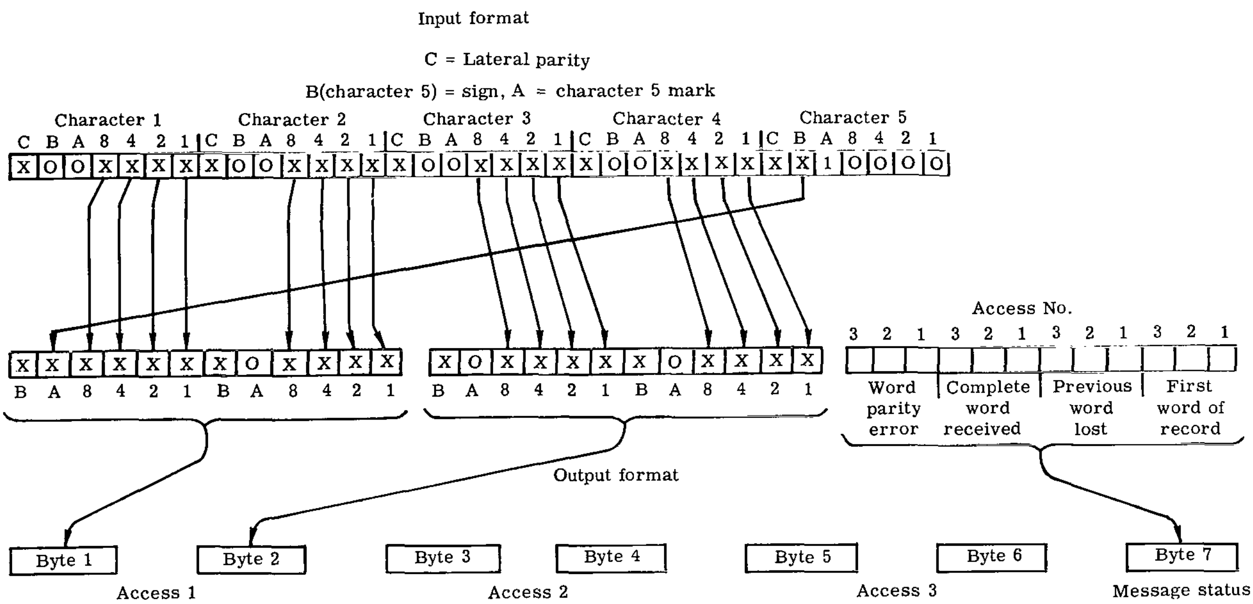

Figure 6.- Interface format conversion.

The time required to transmit five characters to the interface is 333 microseconds. The peripheral processor is programed to read the interface (all three recorders) every 300 microseconds in order to keep pace with the input. However, the recorders are mutually asynchronous and the reading can occur before the assembly of a word from one of them has been completed. Three bits in the message status byte are used to indicate whether the word from each recorder has been completed at the time a reading occurs. The data acquisition software examines these bits and eliminates vacuous readings.

Segment marks and end of file marks signifying compute requests and termination of recording, respectively, are single character records. The coding of these characters is recognized by the hardware and the output word is flagged complete without waiting for the arrival of more characters.

In the event that the data acquisition program is prevented (because of some system malfunction) from reading the interface at the required rate, the replacement of an unread word in the interface by a new word causes a "lost data" bit to be set in the message status byte. The interface also senses and flags the start of a new record, and thus permits the data acquisition software to separate records properly.

An interlock circuit is provided for each recorder to insure that data are not recorded when the computer is not prepared for acquisition. This circuit is enabled by a function code from the computer when the data acquisition software is ready to acquire data from that recorder. The circuit is disabled when the interface recognizes either a segment mark or an end-of-file character. The status of this circuit is indicated at the recorder control console.

DATA ACQUISITION SOFTWARE

Function and Resources

The data acquisition software (refs. 4 and 5) was designed to acquire data from the interfaces to the five data acquisition systems in the central recording facility, sort the data by acquisition system, store the data in disk storage, and inform a quasi-real-time data reduction program of its availability. A separate set of files is maintained for each on-line data acquisition system with each file (within a set) consisting of any number of sequential records followed by a computing request or an end of recording code. Design emphasis was also placed on minimizing the computer resources required, such as central memory and utilization of central processor time, while retaining the flexibility to base the order of connection of the data acquisition systems upon the operational requirements of the test facilities served by the on-line system. The capability within the computer operating system for creating common files that are accessible to any program was used as the vehicle for passing data to the data reduction executive program and as the means of obtaining the external control information. Peripheral processor programs were used to communicate with the data reduction executive as well as with the interfaces.

The data acquisition software consists of one central processor program and five peripheral processor programs whose relationships are illustrated in figure 7. The primary programs are the control and decommutation program operating in the central processor and the data acquisition peripheral processor program.

The latter program operates continually from the time that the control program calls it until the end of on-line operations. The remainder of the peripheral processor programs perform functions that are completed in a short time whenever they are called. Between calls, the peripheral processors used by them are available to other programs.

The control and decommutation program executes as a real-time program at control point 1 of the computer system and has the highest priority in the system. Programs

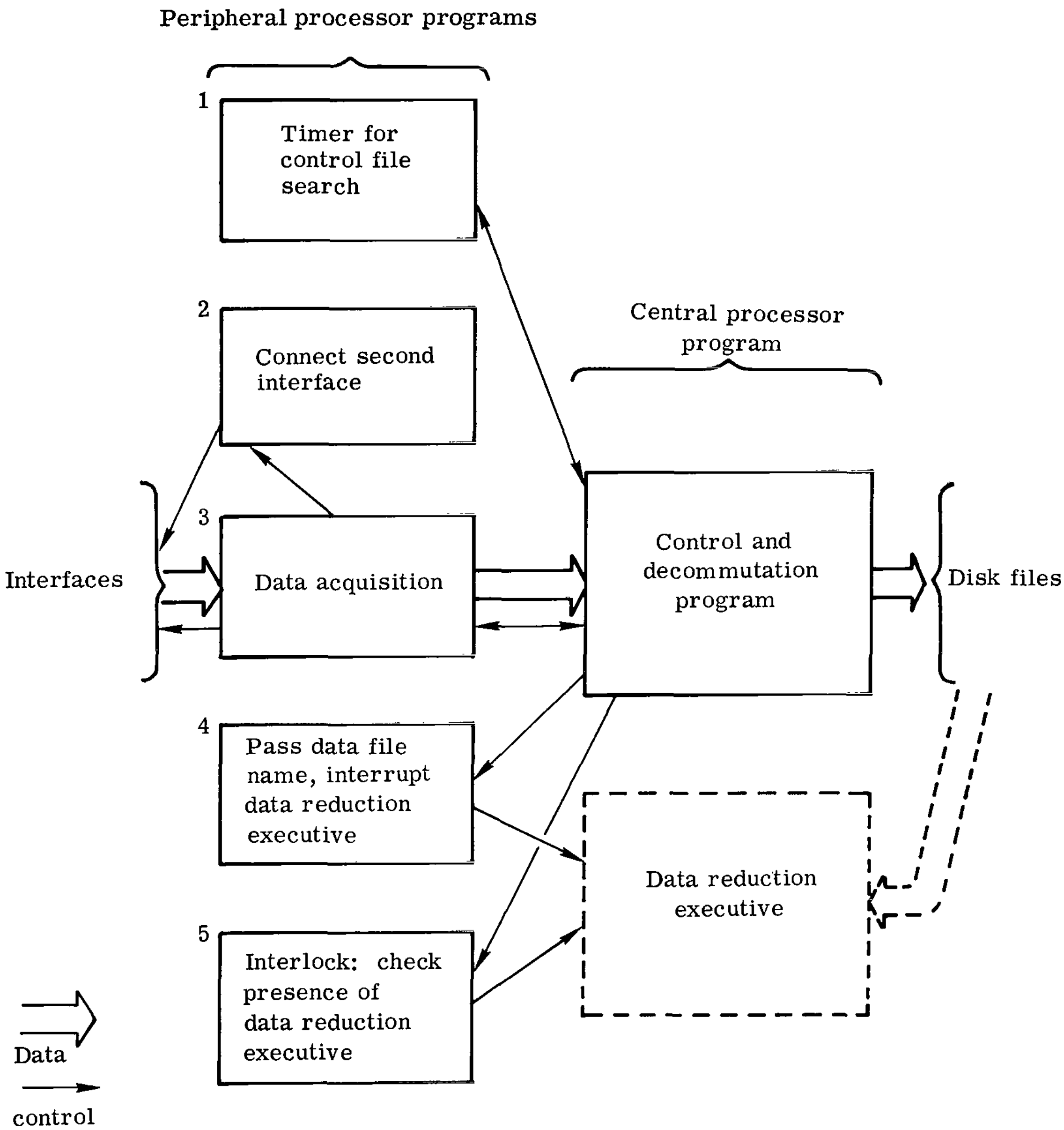

Figure 7.- Data acquisition software.

that execute at control point 1 occupy the lowest ordered area in the computer memory. Their operations are therefore not affected by the memory reallocations that occur as programs at the other control points start, execute, and terminate.

The operating system assigns real-time status to the control and decommutation program and its related peripheral programs for recognition by the monitor. In addition, the operating system prohibits the execution of console operator commands that would interrupt real-time operations.

Two significant priorities are attached to the data acquisition software with regard to data throughput. The acquisition peripheral program has priority over all other peripheral programs with regard to writing into or reading from central memory. The control and decommutation program has priority, over all other central processor programs currently in the computer, for access to disk storage units.

The control and decommutation program is a permanent part of the system library. This program is automatically assigned to control point 1 when a program calling deck is read into the computer. (The data reduction program must be read in at the same time.) At initiation, the control and decommutation program requires 1500 words of memory. Each time a data recorder is brought on-line, an additional memory increment is required for a buffer that holds the decommutated data until it can be transferred to disk storage. The buffers are treated as a pool that is dynamically allocated to the five recorders. This procedure allows the release of a memory increment whenever a facility terminates a recording. The structure of the pool is determined by disk access time. The size of a memory increment is 3200 words.

Control of Operations

After the central processor program is initiated, the previously described external control capability of the system may be utilized to enter information which this program recognizes and responds to.

The control and decommutation program uses a periodically active peripheral processor program (fig. 7, peripheral processor program 1) to establish a reasonable time interval for checking for the presence of the control file in the system. The timing program is activated by the system monitor every 8 seconds. When active, it informs the control and decommutation program that the time interval has elapsed. Before relinquishing the peripheral processor, the timing program arranges for the system monitor to reactivate it at the end of another 8 seconds. This mechanism relieves the control and decommutation program of the necessity of using central processor time for establishing the search interval. The central processor program is inactive when not decommutating data or searching for and responding to control files.

If the control file exists when the search is made, the file will contain either the information needed to establish on-line activity for a recorder or a request to terminate the program execution. In the first case, the file will contain the number of the recorder that is to be activated and the name to be assigned to the first file of data from that recorder. Program termination is described later.

Before acting on the first request to activate a recorder, the control and decommutation program verifies that the data reduction program is present at control point 2 and has established its interrupt table, which is part of the communication line between the programs. This verification is done by means of a peripheral processor program (fig. 7, peripheral processor program 5). The control and decommutation program then opens the designated data file and calls for the data acquisition peripheral processor program.

Data Acquisition Process

A peripheral processor program (fig. 7, peripheral processor program 3) reads the interfaces. The flow of data through this program and the control and decommutation program is illustrated in figure 8. It should be noted that although the peripheral program is continually active in its processor, the control and decommutation program's use of the central processor is intermittent. Discounting the periodic control activity, this program becomes inactive whenever it has emptied its input circular buffer and is reactivated when the peripheral processor program has refilled the buffer to a defined threshold. The unused central processor time is available to the data reduction program and other programs in the computer. It is allocated by the system monitor on a basis of need and priority, data reduction having the highest non-real-time priority.

The logic of the data acquisition peripheral program includes a polling loop and a control loop. The polling loop reads the connected interface unit(s) and transfers the data to central memory. The control loop is used to enable recorder accesses, for communication with the control and decommutation program, and for certain communications with the system monitor. Since the control loop functions are not time critical, this loop is segmented with returns to the polling loop so that the connected interface units can be read every 300 microseconds. However, the function of connecting the other interface cannot be either segmented or fitted into the polling loop timing. Therefore, when the second connection is needed, the data acquisition peripheral program calls for an assisting peripheral program (fig. 7, peripheral processor program 2) to perform the connection.

In the first half of each cycle through its polling loop, the data acquisition peripheral program reads the connected interface units and stores the data in its output circular buffer. Entry into the second half of the polling loop depends upon the status of this buffer. If the amount of stored data is less than a defined threshold, the program executes a

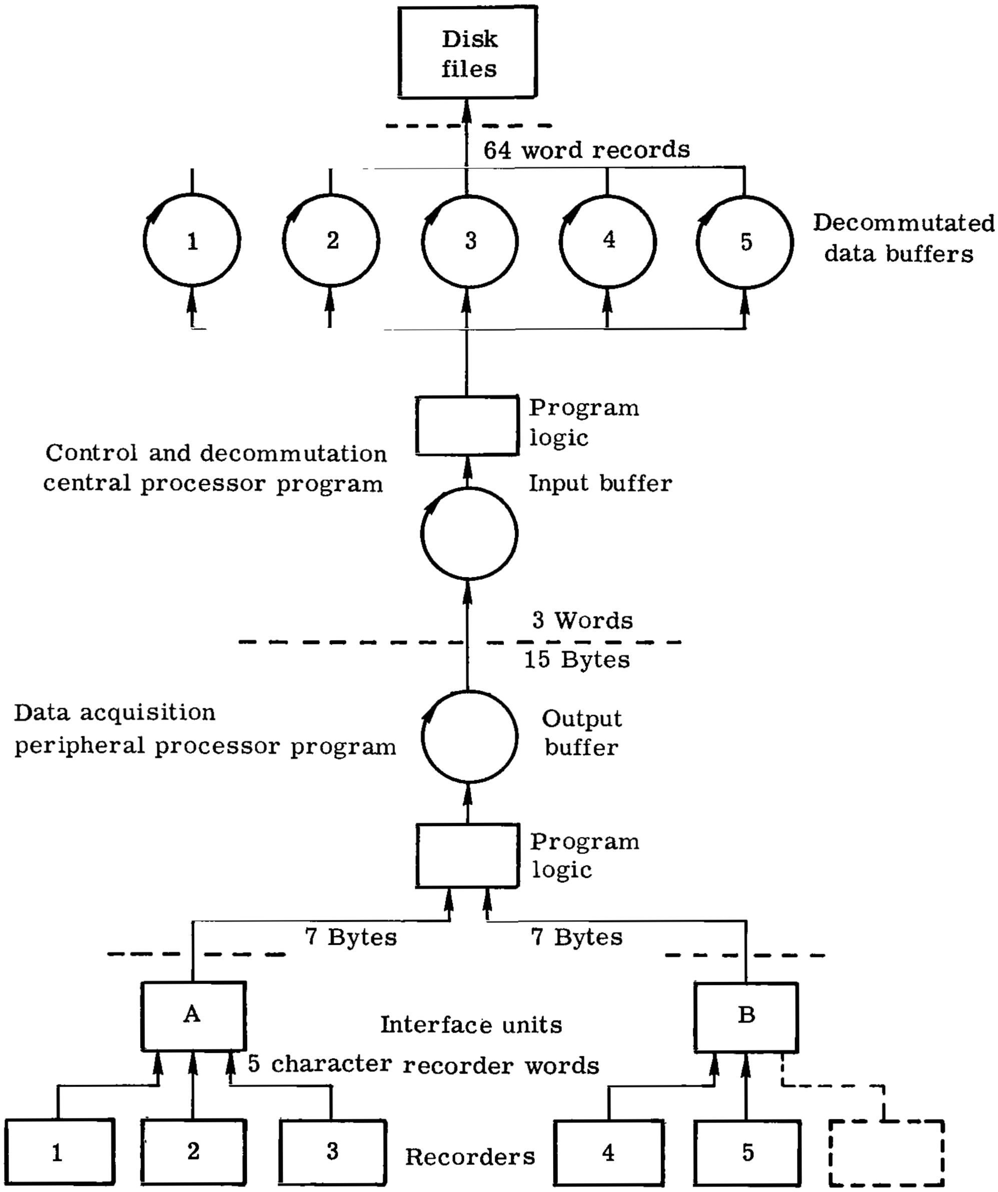

Figure 8.- Input data flow.

segment of the control loop. If the threshold has been exceeded, the second half of the polling loop is entered and the data equivalent of three central memory words is transferred to the input buffer of the control and decommutation program. At this point the peripheral processor program determines whether the control and decommutation program needs to be activated. The peripheral program checks the status of the central memory buffer. If the threshold for activating the control and decommutation program has been reached, the peripheral program initializes the activation. The control and decommutation program proceeds to empty its input buffer and decommutate the data. The circular buffer structure permits the peripheral processor program to transfer additional data during this time. However, the relative speed of the two programs is such that the control and decommutation program will become inactive again in a short time.

It should be noted that the control and decommutation program is not burdened with processing all the readings that are obtained from an interface unit at a rate of one every 300 microseconds. When no actual data are received from the three recorders attached to an interface unit (for example, during concurrent interrecord gaps), the peripheral processor program does not transfer the vacuous information to the central processor program.

Decommutation and Disk Storage

The data in the circular input buffer of the control and decommutation program is in a form that is commutated by recorder. Furthermore, a certain amount of this information is redundant because the interfaces are read more frequently than the data are received from the Beckman data systems. The central processor program removes the redundant information, decommutates the data, and temporarily stores the data for each activated recorder in a separate output circular buffer. The format for a decommutated Beckman record is shown in figure 9. The 120 Beckman words (channels) are packed in 60 central memory (60 bit) words. A three-word header and a one-word trailer contain information related to the entire record. For example, the content of the trailer word indicates whether the record contains parity errors or whether data were lost. Within each half word, 24 bits contain the Beckman data and 6 bits contain control information that is pertinent only to that Beckman channel.

The data in each output circular buffer are transferred to an appropriate file in disk storage whenever a buffer threshold (determined by disk access time) is reached. The 64 central memory words used for each Beckman record constitute the equivalent of a disk sector. Disk data storage and retrieval are done in integral numbers of sectors; thus, this record size is advantageous to the design of the data reduction program. File lengths cannot be predetermined and must therefore be read from the disk in parts.

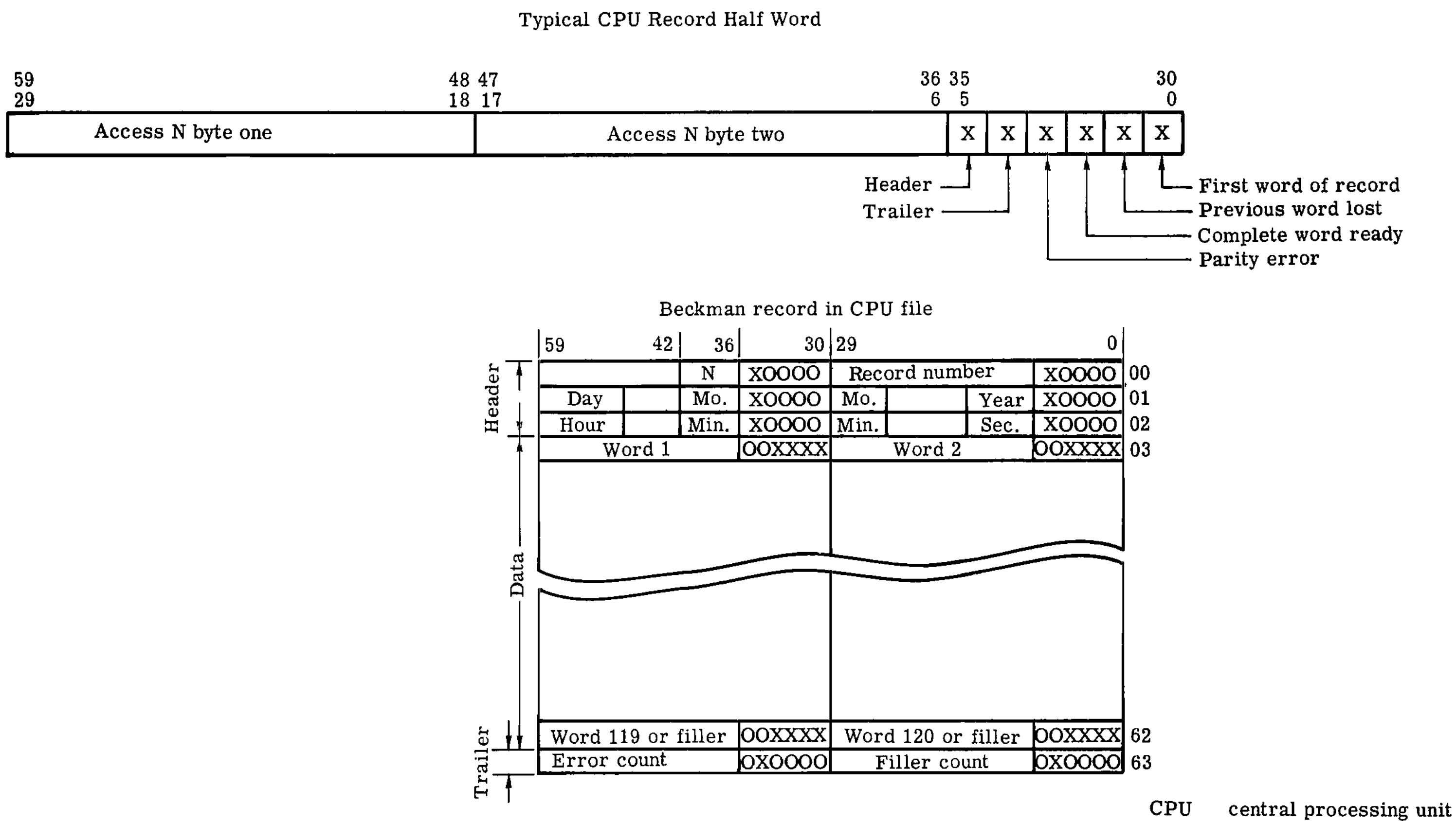

Figure 9.- Beckman record format in central memory.

The chosen size eliminates the need for keeping track of partial records in the data reduction program.

The positional integrity is also preserved in the event of data acquisition malfunctions so that the data reduction program may maintain record-to-record synchronization. In the event of a lost data malfunction, the control and decommutation program uses zero-bit fill to preserve the record size. Conversely, if a malfunction results in an apparent Beckman record of more than 120 channels, the excess words are discarded.

During the decommutation process described, the status flags associated with the data received from the interfaces are examined. Malfunction flags result in the transmission of descriptive messages to the computer display console and to the control terminal of the on-line data system.

Transfer of Data to the Data Reduction Program

When the control and decommutation program detects either a compute request or a recording termination code in the data from a particular recorder, it completes the current data file for that recorder. The remaining data in the output buffer are transferred to disk storage.

The control and decommutation program then informs the data reduction executive program of the availability of this file through a peripheral processor program (fig. 7, peripheral processor program 4) which is used to interrupt the data reduction program. The interrupting program first writes the name of the data file and the number of the recorder from which it came in a memory location within the field length of the data reduction executive program. It then interrupts (by means of the real-time monitor) the data reduction program to complete the transfer. The interrupt response of the data reduction program is checked and its priority is advanced, if necessary. If the data reduction program fails to respond, the data acquisition software transmits appropriate messages to the computer console and the central recording terminal.

If the data file is completed by a compute request, the buffer memory in the control and decommutation program for the related recorder is retained. A new file is opened for the next set of data and the data acquisition peripheral program is instructed to re-enable the interface interlock for that recorder. File names used for on-line data end in a three digit number. The current number is incremented to provide a unique name for the new file.

When a research facility ends its on-line operation, its last file is completed by a recording termination code. The buffer memory for the recorder is returned to the system and the function code to re-enable the interlock is not sent to the interface.

Monitoring and Program Termination

A two-way communication is maintained between the control and decommutation program and the remote terminal located in the central data recording facility. The control and decommutation program routes three types of messages to the terminal: messages indicating normal activity such as the opening of a new data file, messages indicating an invalid operator request (by means of the control file), and messages indicating a system malfunction such as a parity error or lost data condition. The messages are also sent to the computer console display and the system day file.

The periodic search by the control and decommutation program for its control file has been described earlier. When on-line activity for all the recorders has been ended, the program will have relinquished all its output buffer memory. If this condition has occurred and the control file contains the termination request, the execution of the data acquisition software is terminated.

Central Processor Utilization

The central processor time used by the control and decommutation program was measured with the program executing in a Control Data 6600 computer. Total processing time is the sum of the time required for control functions and that used in the decommutation and storage of data. Control function processing time was found to be insignificant (much less than 1 second for an elapsed time of 10 minutes). Since the data acquisition peripheral program deletes a significant amount of the vacuous readings, the central processor time is dependent upon the total number of records received in the period of operation. The central processor time per record ranges from 3.8 to 7.8 milliseconds depending upon the amount of vacuous information that must be processed by the control and decommutation program as a result of data being present from one or more recorders at the instant the interface is read. During periods of maximum recording activity (five active recorders, each operating at 20 records per second), the total central processor utilization ranges from 38 percent to 43 percent.

DATA REDUCTION SOFTWARE

Program Structure and Resources

The data reduction software referred to as the Beckman Executive is user-oriented in its design while taking full advantage of systems programing techniques. The user's programs, subordinate overlays representing various test facilities, concentrate solely on the reduction techniques used by their particular facility. The main overlay, or Executive, provides: (1) the input-output capabilities (in the form of subprograms), (2) file maintenance for each data reduction overlay, (3) error protection and recovery, and (4) methods for updating test parameters for the data reduction overlays.

On-line data reduction is performed by a central processor program, the Beckman Executive, which operates at control point 2. Data reduction overlays are written in FORTRAN and no special consideration has to be made for the fact that they operate in quasi real time. The design of the data reduction software allows the set of data reduction overlays to be changed when the Beckman Executive program is entered into the computer.

The Executive overlay of the program, which contains the control logic and the subroutine which support the data reduction overlays, always occupies central memory space when on-line processing is in progress. The data reduction overlays reside in disk storage when not actually processing data. When called, they communicate with the Executive program through a common memory area. The total memory required for the Beckman Executive program software is determined by the sum of the requirements for the Executive and the largest data reduction overlay being used.

The handling of data reduction overlays in the Beckman Executive program is somewhat different from the usual practice in which overlays are always called from disk storage in their initial status. After a data reduction overlay has been active in the central processor, it is restored in disk storage in its current status. The overlays can therefore be programed to maintain current test parameters or results obtained from processing one data file for use in processing a subsequent data file. The exchanging of data reduction overlays in central memory is automatically accomplished by the operating system. The exchange does not affect the status or operation of an overlay in its next period of operation.

Executive Overlay Functions

The Executive's tasks include: (1) the logical connection of each data reduction overlay to the appropriate Beckman recorder, (2) channeling updated test parameters to the overlays, (3) preparation and maintenance of data files to permit the data reduction overlays to function with a minimum involvement in housekeeping chores, and (4) the provision of subroutines commonly used by the data reduction overlays. A special Executive task is the preservation of the remainder of the on-line data system if a catastrophic error occurs during the execution of any data reduction overlay. Normally, errors occurring during any program's execution – batch or on-line – are fatal to the entire program.

The Executive has five major sections that are used to implement the tasks described. These sections are concerned with: external input communication, internal communication, interrupt logic, a data file index search procedure, and dynamic output. A separate description of each section will clarify the subsequent description of the overall program operation. The protection of the program against failure in an individual data reduction overlay will be presented after describing the normal operation.

External Communication

External communication is accomplished through the use of a connection control file and a parameter control file. These files are created as common files within the computer system. Ordinarily, these files are created by entering a suitable deck in the remote terminal which is located in the central recording facility. The Executive periodically checks for these files. A timing peripheral processor program controls the minimum interval for this check so that the central processor is not used excessively.

The connection control file is used either to initiate on-line activity for a particular research facility or to terminate all on-line activity. In the first case, the file will contain the facility name and the number of the Beckman recorder that has been connected to it. The Executive correlates the facility's data reduction overlay with the specified recorder. When all facilities have terminated on-line processing, the connection control file is used to terminate the operation of the Beckman Executive program.

The parameter control file is used by the central recording facility operator to change constants in a data reduction overlay when requested to do so by a research facility. The Executive directs the constants to the proper data reduction overlay. Control files are purged from the system after their instructions have been followed. The operator may therefore recreate them when he wishes to enter new control information.

Internal Communication

Internal communication constitutes the second major section in the Beckman Executive program. This communication is accomplished through a common area within the program that is accessible by the Executive, the data reduction overlays, and various subroutines used in the program.

The communication between the Executive and the data reduction overlays involves three parameters within this common area. The first parameter is a status word that is used in a bidirectional manner. The Executive uses this status word to define the type and quantity of data to the data reduction overlays. In return, overlays set the status work to indicate to the Executive: a request for additional data from the current file, the completion of processing for the current data file, or the completion of processing of the last file. The last case occurs when the overlay recognizes a termination-of-recording code. It results in the discontinuation of the connection between the overlay and the data recorder.

The second parameter set by the Executive, the line address of the research facility's terminal, is used by the overlays to route computed results to their respective terminals dynamically. Although each overlay is programed for a particular facility, the terminal address depends on the Beckman recorder connected to the facility for a given run.

The third parameter informs the reduction overlay if a lost data indication is included in the current file being processed. This condition occurs only as a result of a system software or a hardware malfunction.

Data Interrupt Logic

The third section of the Beckman Executive program is the data interrupt sequence. This sequence is executed whenever the data acquisition software makes available a new file of data from one of the recorders. As described earlier, a peripheral processor program writes the name of the data file and the number of the acquiring recorder in the Executive's memory field. The peripheral processor program then requests the real-time monitor to interrupt the Executive and transfer its execution to the address which starts the data interrupt sequence. At the start of the interrupt sequence, the Executive saves the information needed to return to the point at which it was interrupted. The new file name is then transferred to the file name stack that is maintained for that recorder. The Executive then requests the real-time monitor to restore it to the point at which it was interrupted and to enable subsequent interrupts.

File Search Procedure

This procedure provides for the orderly selection of data files to be processed. The Executive maintains a circular stack for each of the five Beckman recorders to hold the names of data files that have been received but not processed. A pointer indicates the location for entering the newest name and a count of the names in each stack is maintained. When a data interrupt occurs, the new file name is entered in the appropriate location and the related counter is incremented.

New file names are entered in the order that they are received from the data acquisition software. Since this order is the result of independent activity at five research facilities, the order of the file name entry from all facilities is random. However, files are processed in sequence – one file per turn per facility. The oldest file in a stack is selected first. When a file is selected, its name is removed from the appropriate stack and the related counter is decremented.

Dynamic Output

The Beckman Executive program utilizes the dynamic output capability of the system software to return results to the on-line research facilities while the program (Executive and overlays) remains active in the computer. The output routine of the Executive permits each data reduction overlay to communicate with the remote terminal at its related facility. The Executive also uses the routine to send status messages to the control terminal in the central recording facility.

Program Operation

The data reduction software is entered into the computer as a set consisting of the Beckman Executive program, the data reduction overlays, and a group of test parameters for each overlay; the parameters being pertinent to a particular test condition. The program is automatically assigned to a control point and given real-time status which protects the program against inadvertent computer console operator commands that should only be applied to non-time-critical programs.

The Beckman Executive program flow is described, in general, in figure 10. At initialization, the Beckman Executive first determines from a control card which data reduction overlays have been entered. The Executive then obtains from each overlay the information that will be used when that overlay is called from or returned to disk storage.

Once this information is obtained, the Executive calls each data reduction overlay to read its initial test parameters. When this reading has been completed, the Executive transmits to the control terminal in the central recording area, a message informing the operator that the program is prepared to receive control information.

The Executive's first check for control information is made after the initiation phase is completed. The program checks for the existence (in the computer system) of the connection control file. If this file exists, the Executive makes the specified logical connection between data reduction overlay of the test site and the recorder that is physically connected to the test site. A responding message is sent to the control terminal.

The next step of the Executive is to establish its link to the data acquisition software by defining its interrupt table to the real-time monitor. After this step is completed, the program enters wait status.

The Beckman Executive program may be brought out of wait status for two reasons. One is a periodic return to the central processor every 0.5 second and the other results from an interrupt while the program is in wait status. When return to the central processor is on a periodic basis, the Executive checks for new control information. To keep this check from being performed too frequently, the Executive makes use of a timing peripheral processor program similar to that used by the data acquisition software. If the Executive finds its search flag has been set by the timing program, it again checks for and responds to the connection control file. When this procedure is complete, the Executive searches for the parameter control file. This file includes an identification of the data reduction overlay which is to be updated. The appropriate overlay is called to read the new parameters from the file. Data reduction overlays are programed to route a list of the new parameters to the test-site terminal for verification. The list is copied by a monitor terminal in the central recording area for cross reference between central

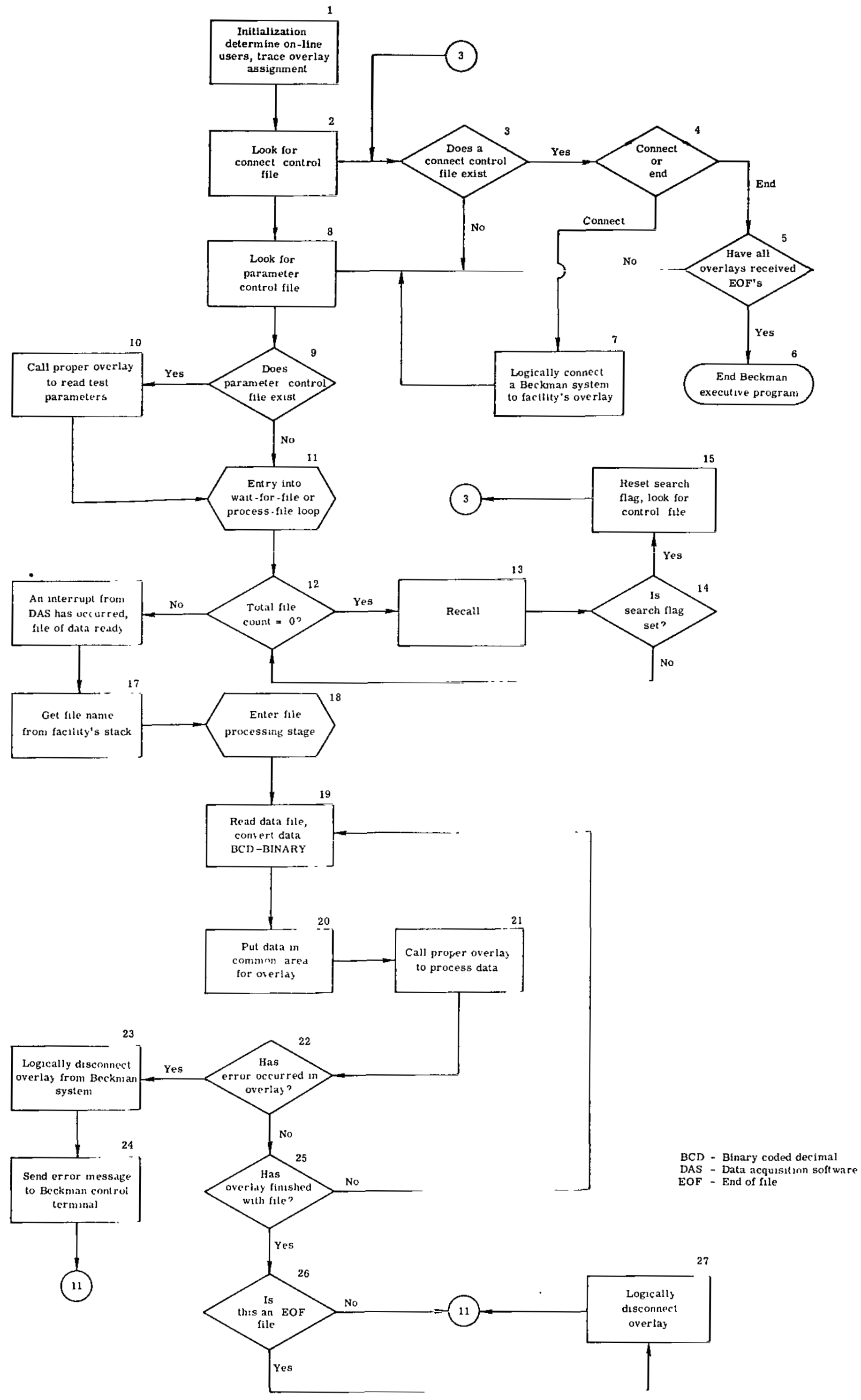

Figure 10.- Executive program general flow.

recording and test site operators. Use of the parameter control file also provides a convenient means of verifying the status of a test site terminal when initiating on-line activity for that site.

The Executive returns to wait status after responding to the control information. Pending the receipt of a data file, the periodic return from wait status and the timing mechanism insures an 8-second response to the introduction of new control information.

The second reason for which the Executive leaves wait status is the receipt of an interrupt from the data acquisition software. The receipt of a data file from the data acquisition software may occur while the Executive is active or while it is in wait status. In either case the interrupt from the data acquisition software will direct the Executive to its file stack maintenance procedure. This procedure involves a check of the total count of data file names (indicating the availability of unprocessed data), and a search of the stacks for the name of the data file which should be processed next.

In determining which data file should be processed, the Executive starts by checking a pointer that indicates which recorder has the next turn for data reduction. Starting with the file stack for this recorder, a sequential check is made until a stack is found that has a nonzero file count. The name of the oldest unprocessed file is extracted and the Executive and the associated data reduction overlay start processing the data.

In processing a data file, the Executive reads a block of 10 Beckman records from disk storage. The data read from disk storage is in the packed format shown in figure 9. The Executive unpacks the record, converts the data to binary integers and stores the data in the Executive overlay communications area – one Beckman channel per computer word. After each 120 data words, a 121st word is set if a parity indicator was found within that record. A single word in the communications area is used to transmit a lost data indication if one should occur anywhere in the data file.

After preparing the first block of data, the Executive calls the required data reduction overlay. The overlay reduces the data as programed and returns control to the Executive. A request for more data is indicated in the internal communication area. The Executive prepares another block of data and the cycle is repeated until all the data in the file have been reduced. The data reduction overlay uses the output routine to direct the results to the remote terminal typewriter at the research facility.

When a given overlay has completely processed a data file, the Executive purges the file from the system to conserve disk storage. The Executive then determines whether the overlay has sensed that the research facility has terminated its on-line activity. If this condition has occurred, the Executive breaks the logical connection between the data reduction overlay and the Beckman recorder. (This condition is necessary for eventual termination of the Executive program's operation.) If the research facility has not terminated its on-line activity, the Executive returns to wait status or to its search for additional on-line data files or parameter control files.

While the reduction of a data file was in progress as described, several events may have occurred with regard to data and control input. Additional data files may have been received from any of the recorders already connected. The operator of the central recording facility may also have used the external control capability to request another recorder-overlay connection or to enter new parameters for an already connected overlay. To satisfy these eventualities, prior to searching the stacks of data file names, the Executive checks for the presence of the connection and parameter control files and acts accordingly. The check for control information at this point permits on-line activity to be established for new facilities even when a previously connected one is quite active in creating data files.

On returning to the stack search logic, the Executive checks the total count of data files. If it is zero, the program returns to wait status. Otherwise, the Executive continues the sequential check of individual stacks until the next data file to be processed is found.

If a different reduction overlay is required (the last used overlay either processed a data file or acquired new parameters), the last used overlay is restored to disk storage and the required overlay is called.

As indicated, on-line activity for a test site may be started at any time by exercising the connection control to link the site data reduction overlay to the recorder that has been physically connected to the site. Once this link has been established, the overlay may have its parameters changed at any appropriate time. Reduction of the available data files by connected overlays is performed sequentially – one file per turn – by recorder number. At some point in time, however, each of the overlays will have sensed a recording termination code and will have permitted the Executive to disconnect it logically. After this point, the Executive will terminate itself if it finds a connection control file with a request to end operations.

Control of Overlay Interaction

The concept of embodying a number of unique data reduction overlays within one program introduced a potential hazard to concurrent multifacility operation since no overlay can ever be considered completely immune to catastrophic error. Catastrophic errors are of two classes. The first includes those which are detected by the computer operating system and normally result in the entire program being aborted. The second class includes errors which result in continuous looping. The looping may be detected by observing a display of a program location register. However, the only recourse is for an operator to drop the program from the computer. In order to guarantee the integrity of the data reduction software if an overlay suffered a catastrophic error, it was necessary to modify the aborting process so that the Executive could disconnect a faulty overlay and continue running. It was also necessary to provide a means whereby the Executive could detect continual looping within an overlay. The control of faulty overlays is done in a manner that does not affect those that are still viable. In addition, the central recording operator is alerted so that he may initiate eventual remedial action. The integrity of the logic within the Executive itself was insured by incorporating check features such as rejecting invalid control statements and by rigorous testing.

The standard aborting process in the Langley operating system has two branches. One handles program attempts to use routines in an invalid manner, such as an attempt to compute the square root of a negative number. The other branch handles invalid hardware usage such as an attempt to divide a quantity by zero.

In the standard aborting process, program usage errors are handled by a routine called SYSTEM. The program routine that is executing detects the invalid usage and gives program control to SYSTEM which does the following: (a) writes an error diagnostic message in the program's output file which describes the type of error and its location in the program, and (b) calls a special system peripheral processor program which aborts the program in an orderly manner. The Executive program uses a modified version of SYSTEM in order to maintain on-line activity for those facilities whose data reduction overlays are still viable. Figure 11 illustrates the program flow for recovery through the use of the SYSTEM routine.

At some point while data are being reduced, an overlay may attempt an invalid use of a routine. As before, the routine involved gives program control to SYSTEM (in this case, the modified version). The modified routine operates in the following manner: (a) writes the error diagnostic in a file specified by the Executive, (b) sets the overlay status word in the program's internal communication area to a value that indicates the occurrence of the error, and (c) returns program control to the Executive as if the return had been made from the data reduction overlay. The Executive examines the status word as it does on each return from overlay. Finding that the status word indicates an error rather than a normal request (for example, for more data), the Executive breaks the logical connection between the overlay and the recorder. Although additional data files from that recorder may exist, the faulty overlay will no longer be called into operation. After disconnecting the faulty overlay, the Executive appends to the error diagnostic file a message which names the test site and indicates the disconnection. The entire file is then sent to the control terminal in the central recording facility. This procedure permits the operator to notify both the research facility and the programer responsible for the data reduction overlay that the malfunction occurred. Operation of all other facilities is unaffected.

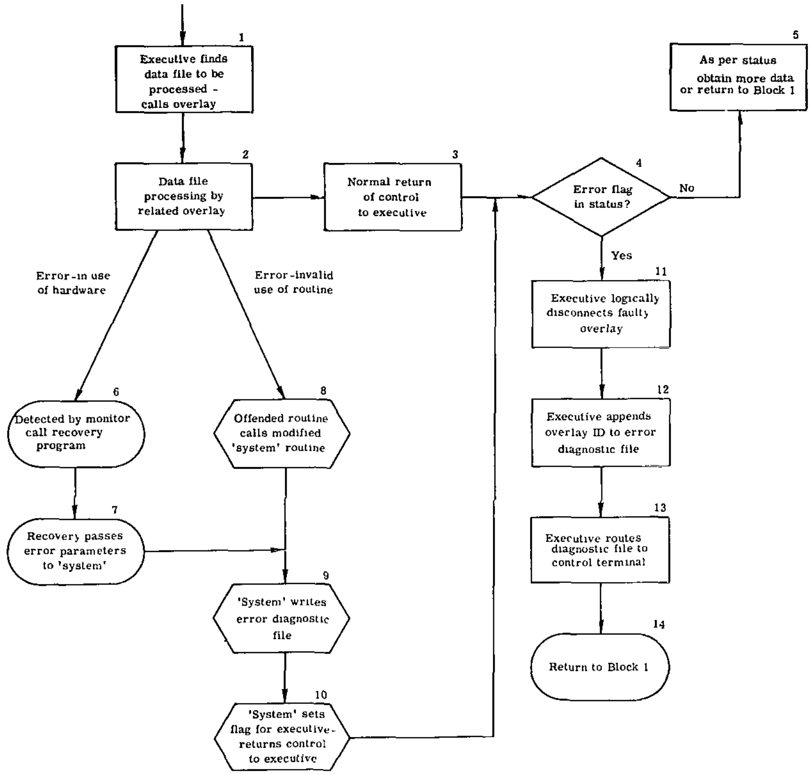

Figure 11.- Executive recovery from catastrophic error in an overlay.

The treatment of errors in hardware usage requires an alternate means of entering the modified SYSTEM routine. This requirement was provided by a special recovery peripheral processor program. A hardware usage error results in the program address register of the Beckman Executive program being set to zero. Upon detecting this condition, the system monitor assigns the recovery program to the Executive's control point. The recovery program transfers control to the SYSTEM routine and passes the error-defining parameters to it. The remainder of the recovery procedure is the same.

The problem of detecting continual looping within a data reduction overlay was not as straightforward since the program steps in such a loop do not result in errors that are detectable by the computer hardware or system software. This problem was overcome by developing an alarm clock arrangement between the Executive program and a loop control peripheral processor program. The program flow for this procedure is described and is illustrated in figure 12.

As indicated in figure 12, when the Executive starts to process a new data file, it stores the file name in the first word of a two-word alarm table. The Executive then calls the loop control peripheral processor program and returns to the data processing activity. The peripheral program equates the second word to the first and is removed from the

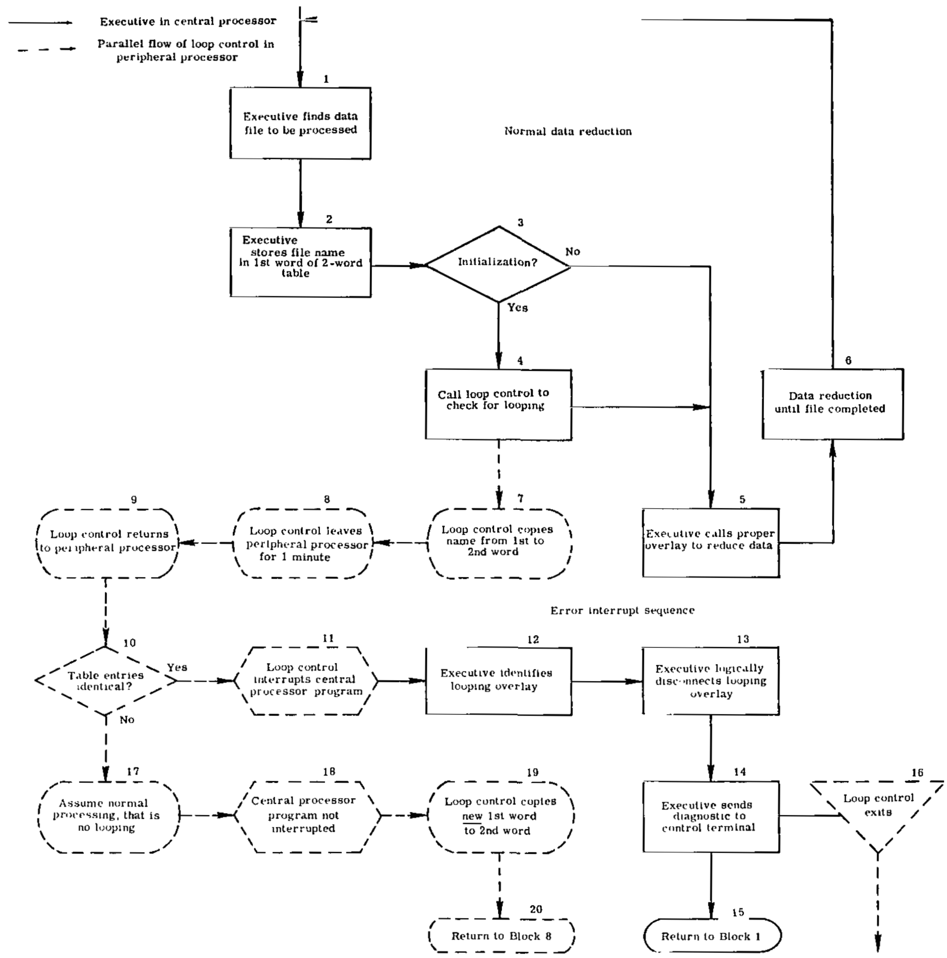

Figure 12.- Recovery procedure for indefinite looping in an overlay.

peripheral processor until 1 minute has elapsed. During this time, the Executive changes the first word of the alarm table each time processing of another data file is started; when all available files have been processed, this location is set to zero.

Upon returning to the peripheral processor, the loop control program checks the table for a condition of a looping overlay as indicated by identical file names. If this condition has not occurred, the first word (if not zero) is again copied into the second table location and the loop control program repeats its 1-minute cycle. If looping has occurred, the loop control program – by means of the real-time monitor – interrupts the Executive and places it at the start of a loop interrupt sequence. The Executive discontinues the connection between the faulty overlay and the data recorder and sends an appropriate message to the control terminal in the control recording area. The looping control is then reinitialized after which the Executive leaves the interrupt sequence and searches for the next file (from another facility) to be processed.

Central Processor Utilization

Computer operational listings were analyzed to determine the amount of central processor time used by the executive overlay for its periodic tasks and for its system maintenance tasks. Accumulated periodic utilization is of the order of 0.12 second per minute of operation. Central processor time per data file is dependent upon the number of records and the particular overlay. A typical value, however, is 0.7 second.

SYSTEM RESPONSE

The response time of the system is considered to be the elapsed time from activation of the compute control at the test site until the start of output at the remote terminal typewriter. Response time has been measured during periods of peak activity of the entire remote terminal subsystem and has ranged from 20 to 25 seconds. It should be noted, however, that most of this time is determined by the speed of the remote terminal subsystem. The particular subsystem used is not an integral part of the on-line system design and can be changed if faster response is needed. Typical elapsed times measured from activation of the compute control until output is available to the remote terminal subsystem range from 5 to 7 seconds.

CONCLUDING REMARKS

The centralized on-line data acquisition and reduction system – implemented as part of the Langley Research Center's digital computer complex – has been in operational use since April 1968. This approach has given a number of test facilities access to a computer system of great computational power during the conduction of aerodynamic tests.

Significant benefits have been realized through the use of the on-line system. Wind-tunnel productivity has been greatly increased by the use of on-line instrument calibration before and during model testing. Invalid runs have been prevented and test-damaged instrumentation has been detected in time to permit re-testing before a new model is placed in the wind tunnel. The use of data reduction overlays which compute aerodynamic performance parameters has been of great value in reducing the number of tests required to determine an optimum configuration. The centralized on-line data system has permitted these benefits to be realized without burdening the test facilities with the operational and maintenance aspects of the computing and data recording facilities.

The techniques described in this paper which were employed to maximize computer resources such as memory, control points, and central processor time available to concurrent non-time-critical programs were quite effective. In a 6-month period, on-line activity took place on 30 days for a total time of 71 hours; 2450 non-time-critical programs were executed during on-line activity. In the same number of hours without on-line activity, 2717 non-time-critical programs were executed. In addition to contributing to the saving of computer resources, the overlay structured data reduction program has been advantageous in integrating new test facilities into the on-line system. The programing and checkout effort required is almost identical to that for a similar off-line program. In most cases, existing data reduction programs were readily converted to overlays.

The on-line system described in this report has met its design goals. However, it is felt that the design of future on-line systems should take into consideration the merits of a higher speed terminal system and remote plotting.

Langley Research Center,
National Aeronautics and Space Administration,
Hampton, Va., September 28, 1970.

APPENDIX

GLOSSARY

Byte	The submultiple of a computer's word size which is used for input and output
Central processor	That part of a computer system containing its main storage, arithmetic units, and registers
Circular buffer	A memory area treated as if the last and first locations were sequential so that concurrent input and output operations can occur
Computer operating system	The integrated set of supervisory software which controls and supports the flow of programs through the computer
Control point	A logical control element within the 6000 computer system that enables computer resources, such as channels, equipment, and central memory, to be used for the execution of a program. A program assigned to a control point is identified by its control point number. There are eight control points, one is reserved for the computer system, the other seven supporting different application programs.
Executive program	A program which controls the operation of a specific set of subordinate routines or programs
Function code	An instruction issued to a peripheral device causing it to execute a particular operation
Multiprograming	A computer operating technique whereby the central processor (arithmetic units and registers) is intermittently used by each of a number of programs that are simultaneously stored in the main memory
On-line processing	The processing of data within seconds of its acquisition by a system that is actively connected to the computer
Overlays	Subprograms structured so that each occupies the same area of main storage when it is executing. The order of overlay operation is directed by the executive part of the program.
Parallel processing	The performance of input and output operations related to a number of programs resident in the main memory in parallel with the computation of another program

Peripheral processor	A processor designed as an integral part of a computer system for communication between input and output equipment and the central processor's memory
Real-time monitor	The controlling program of the computer operating system concerned also with communication and resource allocation. It has a definable and very quick response to the needs of time-critical programs.
Real-time data acquisition	Storage of data in a computer system at a rate determined by one or more external data acquisition (sampling and digitizing) systems

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NASA-Langley, 1970 —— 8 L-6415

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